STANDARDS IDENTIFICATION EXERCISE
RESULTS DOCUMENTATION PACKAGE

Technetium/Cesium Storage

DOE TWRS-P Regulatory Unit

October 27, 1998

Disclaimer

The material contained herein is not intended to be a prescription to be used by the Contractor. It is provided for illustration only, not as formal guidance or as a formal RU position. The Contractor is expected to define, justify, and document the details of its implementation and execution of the Contract-stipulated standards selection process.

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INTRODUCTION

Background

The DOE-sanctioned process for the selection of safety standards is stipulated in the TWRS-P Contract[1]. The standards selection process is to be implemented by the Contractor as defined by Contract documents DOE/RL-96-0004[2] and RL/RU-98-17[3], and the resulting set of standards is to be submitted to the TWRS-P Regulatory Unit (RU) for review and approval in accordance with Contact document DOE/RL-96-0003[4]. The "givens" for the process are the DOE-stipulated top-level safety standards and principles in Contract document DOE/RL-96-0006[5] and all applicable laws and regulations. The performance of the eight essential steps is mandatory--the details of how each step is performed is for the Contractor to define, justify, and document, although elements of an acceptable approach are provided in DOE/RL-96-0004 and elaborated upon in RL/RU-98-17. The outcome of the Contractor's implementation of the DOE-sanctioned process for the selection of safety standards is to be a set safety standards that when properly implemented will provide:

1) Adequate safety;
2) Compliance with applicable laws and regulations; and
3) Conformance to top-level safety standards and principles.

The standards selection process was executed by BNFL during Part A of the TWRS-P Contract. A set of safety standards was submitted by BNFL for review and approval by the RU. The design reached only a low level of maturity during Part A. BNFL's execution of the standards selection process reflected that level of design and therefore the resulting set of standards was approved with a number of conditions, many of which will need to be fulfilled during Part B-1 of the Contract, which is currently underway.

Purpose

The purpose of the standards selection exercise, the results of which are documented herein, was to provide the RU with first-hand experience in executing the Contract-stipulated standards selection process and thereby provide a detailed, informed basis for discussions with BNFL on RU expectations for BNFL's future execution of the process. By executing the process on a specific process element of BNFL's proposed waste processing system (walking in the Contractor's shoes), the RU would have the opportunity to identify and address the detailed decisions and associated challenges involved in initiating the standards selection process

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[1] BNFL Part B Contract
[2] *Process for Establishing a Set of Radiological, Nuclear, and Process Safety Standards and Requirements for TWRS Privatization*, DOE/RL-96-0004; Revision 1.
[3] Regulatory Unit on Tailoring for Safety, RL/RU-98-17, July 31, 1998.
[4] *DOE Regulatory Process for Radiological, Nuclear, and Process Safety for TWRS Privatization Contractors*, DOE/RL-96-0003; Revision 1.
[5] *Top-Level Radiological, Nuclear, and Process Safety Standards and Principles for TWRS Privatization Contractors*, DOE/RL-96-0006; Revision 1.

(e.g., the outcomes), describing the process element (the work), assessing the hazards (the problems), selecting appropriate control strategies (the solution frameworks), and selecting appropriate standards (specific solution approaches).

Scope

The exercise was intentionally very limited in scope. To achieve the purpose of the exercise, a narrow “slice” through the technical steps of the stipulated standards selection process was considered sufficient. The narrow slice was defined as the identification of one significant hazard/event, its assessment, its control through an appropriate control strategy, and selection of implementing standards. This comprises steps 2 through 5 on the Standards Identification Process (DOE/RL-96-0004). The remaining steps of the Standards Identification Process are related to organizational activities of the Contractor and were not considered to be necessary or appropriate for inclusion in this exercise.

The results provided herein are supplemental to the Presentation Package (included herein as Appendix A), which summarizes these results and provides an overview of the reasoning that led to these results. The initial version of the Presentation Package was briefed to BNFL personnel on October 8, 1998.

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ESSENTIAL PROCESS STEP 2--Identification of Work

For this exercise, the Cs/Te Product Storage Tank (V-2710) was selected as the process element on which to execute the Contract-stipulated standards selection process. Hazards associated with this tank were addressed by BNFL in Part A. Thus, some information has been developed and is available in BNFL Part-A documents. In this document, Part A design information is used for illustrative purposes despite the fact that certain aspects of the design have changed as a result of Contract negotiations for Part B. Also, this tank is somewhat unique in that the material it contains is highly radioactive and loss-of-cooling situations can result in hazardous events with substantial consequences to the facility and co-located workers, if uncontrolled.

The descriptive material for the process element has been assembled in Table 1. The goal of assembling this material is to ensure that the information, which is the basis for the hazards evaluation, accurately and sufficiently represents the process element for the execution of the standards selection process.

Table 1. Descriptive Material

ITEM	DESCRIPTION	REFS
Functions	**(What does it do?)** The function of the Cs/Tc concentrate storage tank, V2710 (shown on BNFL Engineering drawing O/BE/1614667 and on the schematic above) is to store technetium and cesium compounds (salts) in aqueous solution for incorporation into the high activity glass. Vessel V2710 is sized to accumulate up to 2-years production of cesium and technetium from processing Hanford Tank Waste in the pretreatment section of the TWRS-P facility, and allows the HLW melter system to commence operation after the low activity melters. Vessel V2710 also provides operational flexibility by permitting the pretreatment operation to continue to separate technetium and cesium from tank waste when high activity melter operations are temporarily suspended, e.g., during melter change-out. The lag storage of technetium and cesium salts in Vessel V2710 permits the blending of the salts into a homogeneous, aqueous mixture before incorporating these radionuclides in the glass. Maintaining a consistent composition of the aqueous cesium/technetium solution to the high level waste melter system should foster the production of glass with predictable properties, and will help minimize process upsets. The technetium/cesium concentrate storage tank contains its aqueous solution of Cs-137 and Tc-99 salts, delivers the solution to the high level melter system when required, vents flammable gases (including hydrogen) generated by radiolysis, and rejects the heat generated by radioactive decay of the Cs-137 and Tc-99 radioisotopes in solution.	

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Processes	**(How does it work?)** The technetium/cesium concentrate vessel V2710 is an atmospheric-pressure tank containing an aqueous solution of radioactive salts at ambient temperature (up to ~100 °C, but normally 50 °C) for the life of the plant, possibly 30 years. The solution normally contains nitric acid at concentrations up to 6 M. The cesium will be present as cesium nitrate; the technetium may be present as either technetium nitrate ($TcNO_3$) or as pertechnate (TcO4-) ions. These technetium and cesium salt solutions will be received from the technetium/nitric acid recovery operation (V2703 Evaporator Kettle, V2706 Tc Concentrate Lute Pot, and V2711 Break Pot), and the cesium/nitric acid recovery operation (V2303 Evaporator Kettle, V2310 Cs Concentrate Lute Pot, and V2402 Break Pot). The homogeneity of the aqueous solution in the tank will be maintained by means of a mixing device. This may be a pneumatic device or could be a mixing paddle driven by an external motor. The cesium/technetium mixture will be pumped out as required to the HLW melter system for blending into the glass. Pneumatically-driven reverse flow diverters (RFDs), immersed in the aqueous solution in the tank, may be used to discharge the liquid. RFDs are low-head pumps with no moving parts, with the advantages of high reliability (therefore low maintenance), and are normally incapable of over-pressuring equipment to which they are coupled. Gases generated by radiolysis of the aqueous solution due to radioactive decay of the cesium and technetium will be vented out of the top of the vessel. The gases will consist of hydrogen chiefly and possibly some nitrogen oxides. If the tank is provided with an overflow port to the surrounding cell, air can be drawn into the tank through the vent so as to maintain the headspace below the lower flammability limit. Whether the tank and its vent system can be designed to ventilate using the natural buoyancy of the flammable gases, or must be provided with a powered, induced-draft ventilation system is presently uncertain. The bubbling at the surface of the solution will release an aerosol of the radioactive solution into the tank headspace and vent system. The headspace of the tank provides a zone for aerosols generated by the breaking of bubbles at the liquid surface to fall back into the liquid. However, the tank vent may require a demister/filter system to capture air-borne particulate materials such as the aerosol and prevent their release to the facility and the environment. The radioactive decay of the Cs-137 and Tc-99 generates by-product heat. Unless this heat can be dissipated, eventually the aqueous solution in the tank will boil, causing the aerosol generation rate to increase above that caused by the breaking of flammable gas bubbles at the liquid surface. In addition, the technetium will likely volatilize out of solution, escape from the vessel, and be carried into the vessel vent system. Even if the volatile technetium is prevented from es-	ISAR Sect. 4.7.2.4.1 and PFDs.

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	caping to the environment by a suitable trap, the technetium compound may plug the vent system. If the Cs/Tc concentrate is permitted to dry out, temperatures may exceed 100 °C and, depending on circumstances may rise to levels sufficient to weaken the V2710 structure and decompose the cesium and technetium compounds to the oxides. Therefore, a system for removing decay heat from the solution must be devised and operated. The diagram of the tank shows cooling coils immersed in the solution, but a variety of coolers is theoretically possible, including, but not limited to (1) external heat transfer to the cell, possibly with extended surfaces e.g., fins, (2) forced convection of the tank contents through an external shell-and-tube-heat exchanger, or (3) cooling the solution with internal cooling coils (possibly with chilled water). Provided that the V2710 vessel is maintained well below the boiling point of the solution (say at 50 °C), several days elapse before tank temperatures rise sufficiently to present operating difficulties. Therefore, 100% uptime for the cooling system for V2710 (totally reliability) is presently believed to be unnecessary.	
Key Parameters	**(How big, how hot, how much pressure, etc.?)** Tank V2710 has a maximum design volume of 56.2 m^3 and maximum radionuclide inventory of 200,000 TBq Cs-137, i.e., 5.405 x 10^6 Ci Cs-137 (not 3.8 x 10^6 Ci as documented in the ISAR Sect. 4.7.2.4.1) and 900 TBq Tc-99, i.e., 2.43 x 10^4 Ci Tc-99. The total heat load is 26 kW as documented in the ISAR and checked with computer software *Radcalc for Windows*, version 1.0. The operating volume in V2710 is 45 m^3. The normal temperature is 50°C. The density of the concentrate is 1250 kg/m^3. The tank solution may contain sufficient HNO_3 to be 6 <u>M</u> nitric acid, and the specific heat of the concentrate is 2.94 kJ/kg °C. The headspace pressure is normally close to atmospheric pressure.	ISAR Rev. 0, Sects. 4.7.1.2.2 and 4.7.2.4.1
Operations	**(What activities required to make it work?)** The feed and discharge lines connected to V2710 must be kept open if the tank is to serve its purpose as a lag storage vessel for Cs/Tc feed to the high hevel waste (HLW) melter system. The mixer in V2710 must be effective in stirring the contents of V2710 to ensure a uniform composition in the feed from V2710 to the HLW melter system. The sampling port must be capable of providing a representative sample of the tank contents for analysis. Reverse flow diverters (RFDs) in the tank must be maintained in operable condition to ensure that the Cs/Tc feed can be delivered to the HLW Melter system at the desired rate. The Technetium Concentrate Transfer Ejector and the Cesium Concentrate Transfer Ejector must be maintained in operable condition and supplied with high-pressure steam to transfer Tc and Cs solutions, respectively, from the corresponding Lute Pots (V2706 and V2310) into V2710 via the Breakpots (V2711 and V2402). The level indicator in V2710 must be operable, and sufficiently accurate to prevent spillover of V2710 contents into the cell, which would necessitate later pumping out the cell back to V2710 once sufficient ullage had been recovered. The	

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	V2710 vent must be maintained open to avoid pressurizing V2710, and possibly causing the unwanted and uncontrolled discharge of the tank contents to the HLW melter system. Tank V2710 radionuclide inventory generates ~26 kW heat from radioactive decay. A volatile technetium compound could be steam-distilled from V2710 if the tank contents were permitted to boil, or approach the boiling point, and could condense in the vent system or escape to the environment. Condensation of the technetium compound in the vent system could restrict the vent and possibly result in uncontrolled discharge of the tank contents to the HLW melter system. Prolonged failure to remove decay heat may permit the concentrate to dry out. The residues may rise to temperatures challenging the integrity of the vessel. The nitrates may decompose, generating NO_x gases and leaving the Cs and Tc as oxides. However, the timely addition of water to the tank would prevent temperatures from exceeding the boiling point. Therefore, the decay heat must be removed by means of a process cooler, and the tank contents maintained at a sufficiently low temperature (50 °C or lower is believed to be acceptable to prevent significant volatilization of the technetium compound.) A reliable process cooling system with adequate heat transfer capability is therefore essential to avoid over-heating the tank. The tank temperature indicator must be in good working order to track tank temperature, monitor the performance of the cooling system, and allow operators time to institute remedial action before boiling starts. The concentration of hydrogen and possibly other flammable gases in the tank headspace must be prevented from approaching the lower flammability limit (~4 vol. % for hydrogen in air), or a deflagration in the headspace and vent system may occur. Therefore, the headspace atmosphere must be inerted (with, e.g., argon, or nitrogen), or swept with sufficient quantities of air to maintain the hydrogen concentration at an acceptably low level (less than 1%). If sweep air is the method chosen to maintain a safe tank headspace atmosphere, the air could be drawn from the hot-cell in which the tank is located, though this is not essential. The flow of dilution air could be either induced by means of a fan (or other device, such as a venturi ejector) in the tank vent system, or the flow might be induced by natural convection (by utilizing the buoyancy of hydrogen in air.) In either case, the source of air must remain unimpeded to guarantee sufficient dilution of the flammable gases to prevent a possible ignition and deflagration. If the source of air is the cell, the port through which the air flows must be maintained unobstructed, e.g., by deposits of a volatile technetium compounds, or by dried-out salts). The same port might serve to spill excessive quantities of technetium and cesium solution into the cell, rather than permitting the liquid to accumulate and spill over into the vent system (which may be shared with other tanks), or over into the HLW melter system. Maintaining a clear flow path through the overflow port is essential to permit the Cs/Tc concentrate storage system to function as intended. A level monitor in V2710 permits operators to track tank level and to take counter-measures to prevent the level rising as high as the overflow port.	
Inventories	**(How much of what--radionuclides, chemicals, physical forms, etc.)**	ISAR Rev. 0, Sect.

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	The maximum radionuclide content of Tank V2710 is 200,000 TBq (5.405 x 10^6 Ci) Cs-137 and 900 TBq (2.43 x 10^4 Ci) Tc-99. Because the half-lives of Cs-137 and of Tc-99 are 30 years and 2.1 x 10^5 years, the quantities of Cs-137 and Tc-99 are calculated to be 62.09 kg and 1413 kg, respectively. If the volume of solution corresponding to these radionuclide inventories is 45 m^3, the calculated Cs-137 concentration will be 1.339 g/L (kg/m^3), and that of Tc-99 will be 31.4 g/L (kg/m^3). The other solution constituents are water and nitric acid (the ISAR assumes 6 <u>M</u> HNO3.) The technetium may be present as the nitrate ($TcNO_3$) or as the pertechnate (TcO_4^-) ion, or both. The relative quantities of the particular species may depend on the concentration of nitric acid present. Various gases besides air are present in the tank. Radiolysis of the solution by alpha, beta, and gamma radiation results in generation of gases, chiefly hydrogen (which is flammable at concentrations in air exceeding ~4 vol. %), but also quantities of NO_x, NH_3 (in alkaline conditions), and oxygen gases. The rate of production of hydrogen depends on the molarity of the nitric acid. If the molarity of nitric acid is zero (water), the 45 m^3 of solution in the tank will generate ~72.3 L/h H_2. For 5 <u>M</u> HNO_3 as the solvent, the corresponding hydrogen generation rate is reduced, to ~4.9 L/h, but oxidizing gases such as NO_x will also be released through radiolysis of the nitrate ions (the rates are not known). The concentration of hydrogen in the tank headspace will depend on the headspace ventilation rate; zero ventilation rate results eventually in 100 % H_2 in the headspace. [Activity (dps or Bq) x radionuclide half-life t (in seconds) = N (no. of atoms of the radionuclide) x ln 2; N = g atoms of radionuclide x Avogadro's Number (6.023 x 10^{23})] *Radcalc for Windows*, Rev. 1.0.	4.7.2.4.1.
Technical Maturity	**(How much experience exists to provide a source of failure tendencies and likelihoods?)** Lag storage of toxic, combustible, and flammable chemical intermediates is very commonly used in chemical processing facilities to facilitate process operability and to accommodate the effect of minor process disturbances. Accumulation of intermediates in lag storage systems (tanks) permits a more consistent composition feed to the process downstream, with the intent to better control the product quality or uniformity. Lag storage of materials that generate flammable gases continuously is very common (e.g., gasoline storage tanks), and is commonly accepted as a standard practice. Lag storage of materials that generate heat by exothermic reaction(s) is less common. Usually, the rate of an exothermic chemical reaction is accelerated by an increase in temperature, so the potential for "runaway" reactions is recognized and handled by the provision of cooling systems sized appropriately for all anticipated processing conditions. The rate of heat generation by radioactive decay in the Tc/Cs Storage Tank is independent of solution temperature, so a "runaway" reaction is not possible as with certain mixtures of chemicals. The Hanford Reservation waste tanks in the tank farms all store radioactive solutions generating decay heat; the "high-heat" and "aging waste" tanks, for example, are kept cool by	

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	means of ventilation air flow through the tank annuli and the headspaces, and can be additionally cooled by the addition of water to the waste, if required. All of the types of equipment elements of the Tc/Cs concentrate storage tank system (coolers, mixers, ventilation systems, etc., have long been employed successfully and effectively to safely store toxic, flammable, and radioactive solutions and muds. What is relatively unusual about the Tc/Cs concentrate storage tank is the size of the projected radionuclide inventory (equivalent to the curie content of 1.8 average Double-Shell Tanks in the tank farms).	
Interfaces	**(To what is the process element connected--possible influence on hazards?)** The Tc/Cs Storage Tank system is connected to (1) the nitric acid/technetium Evaporator Kettle V2703 via the Tc Concentrate Lute Pot and Breakpot V2711; (2) the nitric acid/cesium Evaporator Kettle V2303 via the Cs Concentrate Lute Pot V2310 and Breakpot V2402; (3) the vessel vent system(s), (4) the high activity melter feed system; (5) the high pressure steam (HPS) supply system, (6) Process Air system; (7) the cell in which the V2710 is located for secondary confinement and shielding; (8) the facility ventilation system; and (9) the vessel cooling system(s).	BNFL PFDs 2300, and 2700
Setting	**(What are its immediate neighbors--possible event initiators?)** The Tc/Cs Concentrate Storage Tank V2710 is located in the Low Activity Waste (LAW) Technetium Removal Room at the -14 m elevation (subgrade). The closest vessels are V2706 (the Tc Concentrate Lute Pot), V2603B (Treated LAW Collection Vessel B), and V2603C (Treated LAW Collection Vessel C). Other vessels in the cell include V2603A (Treated LAW Collection Vessel A), V2310 (Cs Concentrate Lute Pot), V2301A (Cesium Eluate Receipt Tank A), V2301B (Cesium Eluate Receipt Tank B), and the 2600 Sump (pump?)	
Miscellaneous	**(Additional information that would be relevant to hazards assessment?)**	

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ESSENTIAL PROCESS STEP 3--Hazards Evaluation

Table 2 contains the results of an abbreviated hazard/event identification process. The hazards/events are grouped in anticipation of selecting bounding events of a particular type, which could be controlled potentially by a common strategy. In the interest of further focusing the exercise, not all hazards/events are included nor are all listed hazards/events fully described. For hazard assessment, event/hazard L-3 was selected. This is an event in which boiling of the tank contents occurs as a result of loss of decay heat removal. The resulting action of vapor bubbles breaking the surface of the liquid in the tank and disintegrating leads to formation of small droplets and entrainment of these droplets into the gases in the tank headspace. The droplets containing radioactive Cs and Tc are then carried from the tank headspace by any air/vapor/hydrogen movement from the headspace. Table 3 provides the general assumptions (those that would apply for the assessment of many different hazards/events for this process element) used in the assessment. Table 4 provides the assessment results, including the specific assumptions used.

The results obtained in this exercise are different than those obtained by BNFL during Part A for the identical hazard/event. This was the result of the interpretation of the data for the rate of droplet generation at the surface of the liquid in the boiling tank. The heating rate from Cs and Tc decay is very low compared to that which is the basis for the available data on radioactive source terms from boiling solutions. In this exercise, the release rate was adjusted to account for the much lower vapor generation rate. Both results are provided for comparison. However, the BNFL results were selected for use in the development of control strategies and selection of standards because they provide better illustration of the approaches used.

Table 2. Hazards Identification Results (hazards and associated events for potentially causing harm)

TYPE	No.	EVENT INITIATOR	EVENT DESCRIPTION	COMMENT
Spill (significant quantity of contents poured out over a short time)	S-1	Loss of level control on Cs/Tc concentrate storage tank (V2710) with over flow during transfer of concentrate from the evaporators	Cs/Tc concentrate spills from near the top of the vessel and falls/rains to the floor resulting in liquid-droplet formation and entrainment in air currents and pooling of the liquid on the floor. Air currents (ventilation airflow or natural convection) transport the entrained radioactive Cs and Tc within the facility and beyond the facility. Facility workers, co-located workers, and the public are the receptors of the consequences of this airborne material. Entrained and evaporated acid is also transported to the same receptors. The pooled liquid on the floor produces direct radiation to workers. Contamination of the facility also would result, adding to facility worker doses	

TYPE	No.	EVENT INITIATOR	EVENT DESCRIPTION	COMMENT
			(clean up and residual contamination during further facility operations) and deactivation doses.	
	S-2	Connecting pipe break during transfer of concentrate from the Cs/nitric acid evaporator to the Cs/Tc concentrate storage tank (V2710) due to corrosion, excessive thermal stress, excessive dynamic fluid forces during transfer, dynamic seismic stresses, etc.	Similar to event S-1 except that the stream of material released is Cs concentrate and the release point could be any location along the connecting piping between the Cs/nitric acid evaporator and tank V2710.	
	S-3	Connecting pipe break during transfer of concentrate from the Tc/nitric acid evaporator to the Cs/Tc concentrate storage tank (V2710) due to corrosion, excessive thermal stress, excessive dynamic fluid forces during transfer, dynamic seismic stresses, etc.	Similar to event S-1 except that the stream of material released is Tc concentrate and the release point could be any location along the connecting piping between the Tc/nitric acid evaporator and tank V2710.	
	S-4	Connecting pipe break during transfer of Cs/Tc concentrate from the Cs/Tc concentrate storage tank (V2710) to Envelope D blending process due to corrosion, excessive thermal stress, excessive dynamic fluid forces during transfer, dynamic seismic stresses, etc.	Similar to event S-1 except that the stream of Cs/Tc concentrate could be released at any location along the connecting piping between tank V2710 and the Envelope D blending equipment.	
	S-5	Gross failure of the Cs/Tc concentrate storage tank (V2710) at maximum inventory during a seismic event	Similar to event S-1	
	S-6	Other		
Leak (continuous loss of contents over many hours)	L-1	Failure in sample line due to corrosion, excessive thermal stress, excessive dynamic fluid forces during transfer, dynamic seismic stresses, etc.	TBD	
	L-2	Crack in the Cs/Tc concentrate storage tank	TBD	

TYPE	No.	EVENT INITIATOR	EVENT DESCRIPTION	COMMENT
		(V2710) due to corrosion, excessive thermal stress, dynamic seismic stresses, etc.		
	L-3	Loss of cooling for removing decay heat from the Cs/Tc concentrate storage tank (V2710)	Cs/Tc concentrate gradually heats up to a temperature at which the energy removed by vaporization of the tank contents equals the decay heat minus heat losses from the tank surface. The vapor leaving the surface of the tank entrains liquid droplets containing Cs/Tc similar to that which occurs in the Tc/nitric acid and the Cs/nitric acid evaporators. The entrained Cs/Tc and nitric acid vapor exits the tank in a continuous manner through a ventilation port (decay heat can't be terminated). Air currents (ventilation airflow or natural convection) transport the entrained radioactive Cs and Tc within the facility and beyond the facility. Facility workers, co-located workers, and the public are the receptors of the consequences of this airborne material. Entrained and evaporated acid is also transported to the same receptors. Contamination of the facility would also result, adding to facility worker doses (clean up and residual contamination during further facility operations) and deactivation doses.	
	L-4	Other		
Pressurized Breach (pressure-driven release of contents over a few minutes)	PB-1	Over-pressure failure of the Cs/Tc concentrate storage tank (V2710) from vent blockage (radiolytic gas generation) or loss of control of process air to pulsejet mixer	TBD	

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TYPE	No.	EVENT INITIATOR	EVENT DESCRIPTION	COMMENT
	PB-2	Flammable gas deflagration (radiolytic decomposition of water) in the Cs/Tc concentrate storage tank (V2710) head-space resulting from insufficient ventilation.	TBD	
	PB-3	Heavy object falling on the Cs/Tc concentrate storage tank (V2710)	TBD	
	PB-4	Other		
Direct Radiation	DR-1	Direct radiation from the Cs/Tc concentrate storage tank (V2710). This radiation is inherent in the material being stored and is present whenever the Cs or Tc exists in this process element.	Direct radiation to workers	
	DR-2	Direct radiation from the connecting lines to Cs/Tc concentrate storage tank (V2710) during Cs/Tc concentrate transfers. This radiation is inherent in the material being transferred and is present whenever the Cs or Tc transfers occur.	Direct radiation to workers	
	DR-3	Other		
Chemical				
Other				

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Table 3. Hazards Assessment--General Assumptions

TYPE	DESCRIPTION OF ASSUMPTION	REFERENCE
Material at risk (MAR) in the Cs/Tc concentrate storage tank (V2710)	MAR is an aqueous solution of cesium nitrate, a technetium compound (which may be the nitrate of technetium or another technetium compound), and nitric acid (HNO_3). The maximum volume of the solution will be ~45 m^3 (in the 56 m^3 capacity vessel). The nitric acid strength will be ~6 M. The maximum inventory of Cs-137 will be 200,000 TBq; the maximum inventory of Tc-99 will be ~900 Tbq.	ISAR, Sect. 4.7.2.4.1
Material at risk in a Cs concentrate transfer to storage tank (V2710)	Cs concentrate lute pot capacity is 0.213 m^3 (213 L). Assuming concentration of cesium in the lute pot is similar to that projected for the Cs/Tc concentrate storage tank, a lute pot full of cesium concentrate will contain 947 TBq Cs-137 in ~6 M nitric acid.	BNFL PFDs
Material at risk in a Tc concentrate transfer to storage tank (V2710)	Tc concentrate lute pot capacity is 0.213 m^3 (213 L). Assuming concentration of technetium in the lute pot is similar to that projected for the Cs/Tc concentrate storage tank, a lute pot full of technetium concentrate will contain 4.26 TBq Tc-99 in ~6 M nitric acid.	BNFL PFDs
Material at risk in the Cs/Tc concentrate transfer from the storage tank (V2710)	Rate of transfer of Cs/Tc concentrate to the HLW melter system is determined by the operating characteristics of the reverse flow diverter (RFD) in the V2710 vessel. The design has not presently set the rate of transfer of concentrate to the melter.	
Dose per unit of Cs/Tc concentrate to a receptor	Assumption: maximum radionuclide content corresponds with maximum volume of aqueous concentrate (more concentrated solutions are possible as the concentrate dries out.) Unit liter dose (C.E.D.E.) (for Cs-137 and Tc-99 components of the concentrate) is 3.848×10^6 rem (sum of the two unit-liter doses documented in the table below.)	DOE/EH-0070, *External Dose-Rate conversion Factors for Calculation of Dose to the Public*
Dose per unit of Cs concentrate to a receptor	Assumption: maximum radionuclide content corresponds with maximum volume of aqueous concentrate (more concentrated solutions are possible as the concentrate dries out.). The tank is assumed to contain 2×10^5 TBq Cs-137. (2×10^5 TBq is 5.405×10^6 Ci because 1 Ci = 3.7×10^{10} Bq.) Assume uniform concentration of Cs-137 in 45,000 L of aqueous solution. 50-year C.E.D.E. (inhalation) for Cs-137 is 3.2 E-02 rem/µCi (8.65×10^{-9} Sv/Bq). Unit liter dose (C.E.D.E.) (for Cs-137 component of the concentrate) is 3.844×10^6 rem.	DOE/EH-0070, *External Dose-Rate conversion Factors for Calculation of Dose to the Public*

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TYPE	DESCRIPTION OF ASSUMPTION	REFERENCE
Dose per unit of Tc concentrate to a receptor	Assumption: maximum radionuclide content corresponds with maximum volume of aqueous concentrate (more concentrated solutions are possible as the concentrate dries out.) The tank is assumed to contain 9 x 10^2 TBq Tc-99. (9 x 10^2 TBq is 2.432 x 10^4 Ci because 1 Ci = 3.7 x 10^{10} Bq.) Assume uniform concentration of Tc-99 in 45,000 L of aqueous solution. 50-year C.E.D.E. for Tc-99 is 7.5 E-03 rem/µCi (2.03 x 10^{-9} Sv/Bq). Unit liter dose (C.E.D.E.) (for Tc-99 component of the concentrate) is 4.054 x 10^3 rem.	DOE/EH-0070, *External Dose-Rate Conversion Factors for Calculation of Dose to the Public*
Location of typical BNFL facility worker	Operating areas, equipment rooms, stores, access corridors, and facility rooms	ISAR Sect. 4.3.6.1 "Process Building HVAC"
Location of most exposed DOE site worker	Assumed ~100 m (scaled from site layout drawing)	ISAR Fig. 1-1 TWRS-P Facility Buildings
Location of most exposed public	9.3 km from facility	HAR Sect. 2.1.3.2 "Transportation"
Dispersion parameters	Atmospheric stability class "F", 1 m/s wind speed, ground level release, open country terrain, no building wake effects, neutral buoyancy plume assumed. At 100m, $\chi/Q = 3.2 \times 10^{-2}$ s/m^3; at 9.3 km, $\chi/Q = 2.8 \times 10^{-5}$ s/m^3	*Turner's Workbook* (*Workbook of Atmospheric Dispersion Estimates*), Figure 3-5F
Exposure parameters	Workers: 8 h; public: 24 h; exposure pathway: inhalation; breathing rate: 1 m^3/h	
Chemical constituents (non-radionuclides)	Nitrate ions, nitric acid (HNO_3), water, hydrogen, air, NO_x	
Chemical concentrations	Nitric acid: 6 M (roughly 38 w/w %); Cs-137 ions: 1.339 g/L; Tc-99: 31.4 g/L	

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Table 4. Hazards Assessment Results—Unmitigated

No.	SPECIFIC ASSUMPTIONS	ESTIMATED MIN CONSEQUENCES			ESTIMATED MAX CONSEQUENCES			ESTIMATED FREQUENCY	
		F-Worker	S-Worker	Public	F-Worker	S-Worker	Public	High	Low
L-3 (This exercise)	Dose received by inhalation pathway is calculated according to the following equation. Dose (rem) = [MAR(L)] x [ARF/h] x [χ/Q(s/m^3)] x [exposure time (h)] x [R.F.] x [breathing rate (m^3/h)] x [unit liter dose (rem/L)]/[3600 (s/h)] Mishima, Schwendiman, and Radasch, in BNWL-931, *Plutonium Release Studies: IV. Fractional Release from Heating Plutonium Nitrate Solutions in a Flowing air Stream,* November, 1968, document the release fractions obtained experimentally for plutonium nitrate from pools of boiling aqueous solutions, with a 2.9 cm/s air sweep over the surface. For each experiment, a 180 mL beaker was charged with 100 mL aqueous plutonium nitrate solution and boiled down to 10 mL ("90% boil-off.") The airborne release fraction was found to be dependent on the degree of disturbance of the liquid surface. The cross-sectional area of the beaker was 11.5 cm$^{2.}$ Under "simmering" conditions (the visual appearance of the solution), the average boil-off rate was 0.6 mL/min, the time to 90% boil-off was 151 min, and the ARF measured was 4.5 x 10^{-4} wt.%, i.e., 4.5 x 10^{-6}. The 0.6 mL/min boil-off rate over the 11.5 cm^2 area of the beaker is equivalent to a steam velocity of 1.48 cm/s perpendicular to the surface at 100 °C. With a "dis-	Not calculated	5.7 x 10^{-2} rem	1.5 x 10^{-4}	Not calculated	22.2 rem	5.8 x 10^{-2} rem	Anticipated	Anticipated

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No.	SPECIFIC ASSUMPTIONS	ESTIMATED MIN CONSEQUENCES			ESTIMATED MAX CONSEQUENCES			ESTIMATED FREQUENCY	
		F-Worker	S-Worker	Public	F-Worker	S-Worker	Public	High	Low
	turbed surface," the boil-off rate was increased, and the ARF increased also. Under "full rolling-boil" conditions (vigorous surface activity) at a higher heat input rate, the average boil-off rate was 1.4 mL/min, the time to 90% boil-off was 63 min, and the ARF measured was 0.18 wt.%, i.e., 1.8×10^{-3}. The 1.4 mL/min boil-off rate over the 11.5 cm^2 area of the beaker is equivalent to a steam velocity of 3.45 cm/s perpendicular to the surface. To select an appropriate ARF for the boiling Cs/Tc concentrate solution in V2710, some measure of the degree of surface disturbance is needed, e.g., "simmering," or "full rolling-boil." The calculated rate of evaporation from the surface, or the calculated steam velocity away from the liquid surface provides a measure of the degree of surface disturbance. In the Cs/Tc concentrate tank V2710, the decay heat release rate = 26 kW (Radcalc software). (1 kWh = 860 kcal; 26 kW = 2.236×10^7 cal/h; latent heat of vaporization of water = 9729 cal/mole). Water evaporation rate assuming all decay heat goes to evaporate water (no heat losses through vessel walls) = 2298.3 moles/h = 41.4 kg/h H_2O. The steam volumetric flow rate at 100 °C = 19.53 L/s = 0.01953 m^3/s. The velocity of steam rising from the liquid surface at								

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No.	SPECIFIC ASSUMPTIONS	ESTIMATED MIN CONSEQUENCES			ESTIMATED MAX CONSEQUENCES			ESTIMATED FREQUENCY	
		F-Worker	S-Worker	Public	F-Worker	S-Worker	Public	High	Low
	100 °C (assuming vessel diameter is 4.8 m) = 0.107 cm/s. This velocity is only 7% of the velocity calculated for the "simmering" plutonium nitrate solution in Mishima *et al*'s "simmering" experiments. Therefore, the surface of the boiling solution in V2710 will be considerably less disturbed even than that of the aqueous plutonium nitrate. The calculated minimum time to boil to 90% dryness (i.e., 90% of 45 m^3 H_2O is boiled off) in V2710 is ~ 40.5/0.0414 = 978 h (assuming all the decay heat goes to vaporize water) *vs* 150 min (2.5 h) for the "simmering" plutonium nitrate in Mishima *et al*'s experiments, for which the ARF was 4.5×10^{-6} (data in BNWL-931). For a "low" estimate of ARF/unit time, assume that the rate at which a fraction equal to 4.5×10^{-6} of the Cs/Tc concentrate becomes airborne is constant over the 978 h period to 90% boil-off; the fraction which becomes airborne in one hour is therefore unlikely to be greater than (4.5×10^{-6})/978 h = **4.6×10^{-9} /h.** This is the "**low**" estimate of ARF per unit time for the boiling Cs/Tc concentrate in V2710. For a "high" estimate of ARF per unit time for the boiling Cs/Tc concentrate in V2710, we could argue that in Mishima *et al*'s experiment involving simmering plutonium nitrate solution, if the concentrated solution remaining after 90%								

No.	SPECIFIC ASSUMPTIONS	ESTIMATED MIN CONSEQUENCES			ESTIMATED MAX CONSEQUENCES			ESTIMATED FREQUENCY	
		F-Worker	**S-Worker**	**Public**	**F-Worker**	**S-Worker**	**Public**	**High**	**Low**
	boil-off, i.e., after 2.5 h, had been diluted with water back to its initial volume of 100 mL, and the experiment repeated, another fraction = ~4.5×10^{-6} would have become airborne, and so on *ad infinitum*. Therefore the "**high**" estimate of ARF per unit time is $(4.5 \times 10^{-6})/2.5$ h = **1.8×10^{-6}/h**. Respirable fraction (RF) = 1 (bounding value from DOE-HDBK-0013-93). This is the fraction of the aerosol in which the droplets have diameters less than 10 micron. The “respirable” droplets can penetrate deeply into the bronchial tract and be absorbed through the epithelial tissue into the body of the receptor.								
L-3 (BNFL)	Key difference is the ARF of 0.002 from Section 3.2.1.2 of DOE-HDBK-0013-93.	Not calculated	Not calculated	Not calculated	Not calculated	1360 rem	1.2 rem	Unlikely	Unlikely

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ESSENTIAL PROCESS STEP 4--Development of Control Strategies

Table 5 illustrates a number of potential strategies that could be applied to address the risk associated with L-3. The strategies are designated L-3-A, L-3-B, etc. (For each potential hazard control strategy, a set of functional requirements is defined in Table 5 based on the primary elements of the strategy, the degree of prevention or mitigation necessary to effectively control the hazard/event, the target reliability that needs to be associated with the strategy elements, and the assurance level that needs to be associated with the strategy. Based on these functional requirements, the potential strategies were evaluated against the top-level principles. Conformance was judged in accordance to the need to have high assurance, which for this exercise is defined in accordance Table 6. The metrics in Table 6 describe the degree to which key top-level principles are invoked to provide high assurance. Tables 7a, b, and c document the evaluation against the applicable top-level principles. Evaluations of representative potential strategies are included for illustration. For easy referral, the applicable top-level safety principles from DOE/RL-96-0006 are included following each of the evaluation tables. Table 8 provides a summary of the evaluation results. Note that a conforming strategy is one for which there is conformance to all applicable principles.

The engineering assessment to determine the practicality of the hazard control strategy that has been judged to be in conformance with the top-level principles is summarized in Table 9. This assessment is intentionally incomplete because it involves considerations of more global hazard control strategies beyond the scope of this exercise. Such assessments are intended to address practical engineering considerations at the local, area-wide, and plant-wide levels.

The selected strategy is described in Table 10. It is further delineated in term of key strategy elements and key provisions associated with each element and ultimately in terms of functional requirements at the feature/provision level as shown in Table 11. These tables are intentionally incomplete because the engineering considerations associated with selected strategy elements can not been completed apart from consideration of other hazards/events to which the same strategy may be applied. Whenever a global strategy is selected, the functional requirements for the associated features/provisions need to be selected such that they envelope the functional requirements and operating environments of all hazard control strategies to which it applies.

The approach used in this exercise maintains a clear linkage between the individual hazard/event, the selected strategy (whether it be a dedicated strategy, a local strategy, an area-wide strategy, or a plant wide strategy), the selected strategy elements and associated features/provisions, and the functional requirements at the feature/provision level. This provides the means to ensure that all identified hazards/events are associated with a strategy and that associated strategies are efficacious in controlling the identified hazards/events.

Table 5. Potential Strategies

No.	DESCRIPTION	FUNCTIONAL REQUIREMENTS			
		Prevention	**Mitigation**	**Reliability**	**Assurance Level**
L-3-A	Single active cooling system to remove decay heat	frequency of event reduced to less than 10^{-6} per year	none	probability of strategy failure less the 10^{-6}	**High** because failure of hazard control translates to a potential for lethal doses to facility and nearby site workers
L-3-B	Single passive cooling system to remove decay heat	same as A	none	same as A	same as A
L-3-C	Single active cooling system to remove decay heat with sensing and notification of degraded cooling (tank temperature rise, loss of cooling system flow, etc.) coupled with reparability, which is made possible by engineered access and by the slow heat-up rate	same as A	none	probability of strategy failure less the 10^{-6} but reduced reliability of active cooling system commensurate with reliability of human actions to repair in available time interval	same as A
L-3-D	Single active cooling system to remove decay heat with sensing and notification of degraded cooling (tank temperature rise, loss of cooling system flow, etc.) coupled with transfer of concentrate to a cooled, backup tank, which is made possible by the slow heat-up rate	same as A	none	probability of strategy failure less than 10^{-6} but reduced reliability of active cooling system commensurate with reliability of active transfer in available time interval	same as A

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L-3-E	Single active cooling system to remove decay heat with frequent inspection, testing, and maintenance, which is made possible by the slow heat-up rate	same as A	none	probability of strategy failure less the 10^{-6} but reduced reliability of active cooling system commensurate with reliability and effectiveness of human actions to inspect, test, and perform maintenance in available time interval	same as A
L-3-F	Multiple independent trains of active cooling to remove decay heat--all fully capable	same as A	none	probability of strategy failure less than 10^{-6} but reliability of each train divided among the trains	same as A
L-3-G	Water makeup and filtration of the vapor stream from vessel	none	decontamination factor of >200	probability of strategy failure less the 10^{-6}	same as A
L-3-H	Water makeup and filtration of the vapor stream from vessel with sensing and notification of degraded filters (radiation monitor down stream of filter, filter pressure difference, etc.) coupled with reparability or bypass to a second filter, which is made possible by engineered access and by the slow heat-up rate	none	decontamination factor of >200	probability of strategy failure less than 10^{-6} but reduced reliability of filter system commensurate with reliability of human actions to repair/bypass in available time interval	same as A

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L-3-I	Backup active cooling system to remove decay heat plus filtration of vessel off-gases	frequency of event reduced to less than 10^{-3} per year	decontamination factor of >40	probability of strategy failure less than 10^{-6} but reliability of the two strategy elements divided among the elements	same as A
L-3-J	Single active cooling system to remove decay heat plus local isolation of the area	frequency of event reduced to less than 10^{-3} per year	reduction of release of radionuclides by a factor of >40	probability of strategy failure less than 10^{-6} but reliability of the two strategy element divided among the trains	same as A
L-3-K	Other				

Table 6. Characteristics Needed for High Assurance

Assurance Considerations	Characteristics Needed
Degree of defense in depth (TL Principle 4.1.1.1)	Two fully capable, independent means be provided to control the hazard
Degree of proven practices (TL Principle 4.2.2.1)	Be implementable through features/provisions for which specific experience can be cited to attest to their ability to deliver the functions required at the reliability needed
Degree of diversity (mix of prevention/mitigation) (TL Principle 4.1.1.2 and 4.1.1.3)	Defense in depth features be provided for mitigation as a backup to prevention
Degree of automation (TL Principle 4.1.1.5)	Safety features/provisions requiring rapid activation under accident conditions be fully automated
Degree of passiveness (TL Principle 4.2.5)	Active features/provisions acceptable--use passive if it can be cost-effectively accomplished
Degree of operations control (TL Principle 4.1.1.3)	Operations controlled such that the need for hazards controls features/provisions is not an anticipated event
Degree of human reliance (TL Principles 4.1.1.6, 4.2.3.2, 4.2.4.1, 4.2.6.1, 4.2.6.2, and 4.2.6.3)	Minimal reliance on human actions as hazard control provisions (perform or actuate hazard control functions) unless the situation is amenable to reliable human performance because of long action intervals and low complexity

Table 7a. Evaluation of Potential Strategies Against Applicable Top-Level Principles

No.	Evaluation Elements				
	Defense in Depth (4.1.1.1)	Prevention (4.1.1.2)	Control (4.1.1.3)	Mitigation (4.1.1.4)	Automatic (4.1.1.5)
L-3-A	**NC**. All protection is vested in single cooling system	**C**. Emphasis is fully on prevention	**C**. Requires that heat generation rate be within limits--inventory limits for Cs and Tc	**NC**. High assurance requires mitigation for diversity of control	**NA**. Not applicable because additional hazard-control actions are not a strategy element
L-3-B	**NC**. All protection is vested in single cooling system	**C**. Emphasis is fully on prevention	**C**. Requires that heat generation rate be within limits--inventory limits for Cs and Tc	**NC**. High assurance requires mitigation for diversity of control	**NA**. Not applicable because additional hazard-control actions are not a strategy element
L-3-C					
L-3-D					
L-3-E	**NC**. All protection is vested in single cooling system	**C**. Emphasis is fully on prevention	**C**. Requires that heat generation rate be within limits--inventory limits for Cs and Tc	**NC**. High assurance requires mitigation for diversity of control	**NA**. Not applicable because additional hazard-control actions are not a strategy element
L-3-F	**C**. At least 2 fully capable, independent cooling systems provided	**C**. Emphasis is fully on prevention	**C**. Requires that heat generation rate be within limits--inventory limits for Cs and Tc	**NC**. High assurance requires mitigation for diversity of control	**NA**. Rapid activation of independent cooling systems is not necessary because of the slow heat-up rate of the contents of the tank.
L-3-G					
L-3-H					
L-3-I	**C**. Two fully capable, independent means of control provided.	**C**. Emphasis is provided on prevention through the provision of a fully capable, independent backup cooling system	**C**. Requires that heat generation rate be within limits--inventory limits for Cs and Tc	**C**. Both prevention and mitigation provisions are provided	**NA**. Rapid activation of independent cooling system or the independent off-gas filtered-ventilation system is not necessary because of the slow heat-

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No.	**Evaluation Elements**				
	Defense in Depth (4.1.1.1)	Prevention (4.1.1.2)	Control (4.1.1.3)	Mitigation (4.1.1.4)	Automatic (4.1.1.5)
					up rate of the contents of the tank.
L-3-J					
L-3-K					

NC – Non-conforming, C – Conforming, NA – Not Applicable, CC - Conformance Challenge

4.1.1.1 Defense in Depth — To compensate for potential human and mechanical failures, a defense-in-depth strategy should be applied to the facility commensurate with the hazards such that assured safety is vested in multiple, independent safety provisions, no one of which is to be relied upon excessively to protect the public, the workers, or the environment. This strategy should be applied to the design and operation of the facility.

4.1.1.2 Prevention — Principle emphasis should be placed on the primary means of achieving safety, which is the prevention of accidents, particularly any that could cause an unacceptable release.

4.1.1.3 Control — Normal operation, including anticipated operational occurrences, maintenance, and testing, should be controlled so that facility and system variables remain within their operating ranges and the frequency of demands placed on structures, systems, and components important to safety is small.

4.1.1.4 Mitigation — The facility should be designed to retain the radioactive material through a conservatively designed confinement system for the entire range of events considered in the design basis. The confinement system should protect the workplace and the environment.

4.1.1.5 Automatic Systems — Automatic systems should be provided that would place and maintain the facility in a safe state and limit the potential spread of radioactive materials when operating conditions exceed predetermined safety set-points.

Table 7b. Evaluation of Potential Strategies Against Applicable Top-Level Principles

No.	**Evaluation Elements**				
	Human Aspects (4.1.1.6)	Proven Practices (4.2.2.1)	Criticality (4.2.2.5)	Rad Protection Features (4.2.3.2)	DDD Design (4.2.3.3)
L-3-A	**NA**. Human activity is not a strategy element	**NC**. Achieving the needed high reliability in a single active cooling system is not proven technology	**NA**. Not applicable because fissile material not collected on ion-exchange resins	**NA**. Not applicable because human activity is not a strategy element	**C**. No material leaves the containing barrier
L-3-B	**NA**. Human activity is not a strategy element	**NC**. Achieving the needed high reliability in a single passive cooling system is not proven technology	**NA**. Not applicable because fissile material not collected on ion-exchange resins	**NA**. Not applicable because human activity is not a strategy element	**C**. No material leaves the containing barrier
L-3-C					
L-3-D					
L-3-E	**NC**. Heavy reliance on human actions associated with inspection, testing, and maintenance leaving substantial opportunity for limited confidence.	**NC**. Achieving the needed high reliability in a single active cooling system with rigorous inspection, testing, and maintenance is not proven technology/approach	**NA**. Not applicable because fissile material not collected on ion-exchange resins	**CC**. Parts of the cooling system (piping) will be in a high rad field near the vessel. Inspecting this part of the system for degradation will require remote techniques to protect workers. Conformance to this principle will result in design challenges which in turn will tend to undermine achievement of the high assurance of suc-	**C**. No material leaves the containing barrier

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No.	Evaluation Elements				
	Human Aspects (4.1.1.6)	Proven Practices (4.2.2.1)	Criticality (4.2.2.5)	Rad Protection Features (4.2.3.2)	DDD Design (4.2.3.3)
				cess needed.	
L-3-F	**C**. Human action to actuate the independent cooling systems on demand should not pose significant challenges to assurance of success because of the extended time available to determine and respond to the demand for backup cooling.	**CC**. The individual reliability of the multiple, independent cooling systems would be challenging to achieve with assurance.	**NA**. Not applicable because fissile material not collected on ion-exchange resins	**C**. Human activity is involved in the strategy in activating backup cooling, but this can be done outside of rad fields.	**C**. No material leaves the containing barrier
L-3-G					
L-3-H					
L-3-I	**C**. Human action to actuate the independent cooling system and ventilation system on demand should not pose significant challenges to assurance of success because of the extended time available to determine and respond to the demand for backup cooling or ventilation.	**C**. The individual reliability of the independent cooling system and ventilation system should not be challenging to achieve with assurance.	**NA**. Not applicable because fissile material not collected on ion-exchange resins	**C**. Human activity is involved in the strategy in activating backup cooling and ventilation, but this can be done outside of rad fields.	**C**. No material leaves the containing barrier except for that deposited/collected in the ventilation system, which would be in a controlled state.
L-3-J					
L-3-K					

NC – Non-conforming, C – Conforming, NA – Not Applicable, CC - Conformance Challenge

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4.1.1.6	Human Aspects	The human aspects of defense in depth should include a design for human factors, a quality assurance program, administrative controls, internal safety reviews, operating limits (Technical Safety Requirements), worker qualification and training, and the establishment of a safety/quality program.
4.2.2.1	Proven Eng Practices	Safety technologies incorporated into the facility design should have been proven by experience or testing and should be reflected in approved codes and standards. Significant new design features should be introduced only after thorough research and model or prototype testing at the component, system, or facility level, as appropriate.
4.2.2.5	Criticality	The facility should be designed and operated in a manner that prevents nuclear criticality.
4.2.3.2	Rad Prot Features	At the design stage, radiation protection features should be incorporated to protect workers from radiation exposure and to keep emissions of radioactive effluents ALARA and within prescribed limits.
4.2.3.3	D, D, and D Design	The design of the facility should incorporate provisions to facilitate deactivation and the final decommissioning. The objective of these provisions should be to reduce radiation exposures to Hanford Site personnel and the public both during and following deactivation and decommissioning activities and to minimize the quantity of radioactive waste generated during deactivation, decontamination and decommissioning.

Table 7c. Evaluation of Potential Strategies Against Applicable Top-Level Principles

No.	**Evaluation Elements**				
	Support Facilities (4.2.4.1)	Inherent/Passive (4.2.5)	Human Error (4.2.6.1)	Instrumentation & Control (4.2.6.2	Safety Status (4.2.6.3)
L-3-A	**NA**. Human activity is not a strategy element	**C**. Reliable active systems are acceptable for the assurance regime needed.	**NA**. Human activity is not a strategy element	**NA**. Human activity is not a strategy element	**NA**. Human activity is not a strategy element
L-3-B	**NA**. Human activity is not a strategy element	**C**. Reliable active systems are acceptable for the assurance regime needed.	**NA**. Human activity is not a strategy element	**NA**. Human activity is not a strategy element	**NA**. Human activity is not a strategy element
L-3-C					
L-3-D					
L-3-E	**NA**. Human activity is a strategy element but only as a prevention measure. Human actions during the accident are not intended.	**C**. Reliable active systems are acceptable for the assurance regime needed.	**CC**. Human error will be a concern in the inspection, testing, and maintenance actions. Designing to minimize the potential for human error and therefore achieving conformance to this principle will result in substantial challenges in establishing the high assurance of success needed.	**CC**. The inspection and testing instrumentation will be challenging to design and use because some testing and inspection will need to be performed remotely because of high rad fields.	**CC**. The statusing instrumentation and displays should be standard practices (temperature of the vessel, heat removal rate, flow rate, loss of cooling fluid, etc.).
L-3-F	**C**. Should not be a conformance challenge because the human actions involved occur well before any potential for habitability concerns.	**C**. Reliable active systems are acceptable for the assurance regime needed.	**C**. Should not be a conformance challenge because the human actions involved are not complex or hurried--ample time to detect human errors and to take corrective action.	**C**. Should not be a conformance challenge because the instrumentation for indicating the need to activate backup cooling systems/trains is standard practice.	**C**. Should not be a conformance challenge because the instrumentation for indicating the status of backup cooling systems/trains is standard practice.

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No.	Evaluation Elements				
	Support Facilities (4.2.4.1)	Inherent/Passive (4.2.5)	Human Error (4.2.6.1)	Instrumentation & Control (4.2.6.2	Safety Status (4.2.6.3)
L-3-G					
L-3-H					
L-3-I	**C**. Should not be a conformance challenge because the human actions involved occur well before any potential for habitability concerns.	**C**. Reliable active systems are acceptable for the assurance regime needed.	**C**. Should not be a conformance challenge because the human actions involved are not complex or hurried--ample time to detect human errors and to take corrective action.	**C**. Should not be a conformance challenge because the instrumentation for indicating the need to activate backup cooling system and ventilation system is standard practice.	**C**. Should not be a conformance challenge because the instrumentation for indicating the status of backup cooling system and ventilation system is standard practice.
L-3-J					
L-3-K					

NC – Non-conforming, C – Conforming, NA – Not Applicable, CC - Conformance Challenge

4.2.4.1 Support Facilities — The facility design should provide additional capability to place and maintain the facility in a safe state following an accident if the normal control areas are expected to become uninhabitable.

4.2.5 Inherent/Passive — Design features that enhance safety through simplified, inherent, passive, or other highly reliable means to accomplish safety functions should be employed to the maximum extent practicable.

4.2.6.1 Human Error — The possibility of human error in facility operations should be taken into account in the design by facilitating correct decisions by operators and inhibiting wrong decisions and by providing means for detecting and correcting or compensating for error.

4.2.6.2 I and C Design — Sufficient instrumentation and control capability should be provided so that under normal operating and postulated accident conditions the operators can diagnose facility conditions, place and maintain the facility in a safe state, and mitigate accidents. If necessary, measures should be provided to protect the operator in the performance of these functions.

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4.2.6.3	Safety Status	Parameters to be monitored in the control room should be selected and their displays should be arranged to ensure that operators have clear and unambiguous indications of the status of facility conditions important to safety, especially for the purpose of identifying and diagnosing the actuation and operation of a system or components important to safety.

Table 8. Evaluation of Potential Strategies Against Applicable Top-Level Principles - Conformance Summary

No.	Evaluation Elements															Acceptability/Comments
	Defense in Depth	Prevention	Control	Mitigation	Automatic	Human Aspects	Proven Practices	Criticality	Rad Prot Features	DDD Design	Support Features	Inherent Passive	Human Error	Instr & Control	SafetyStatus	
L-3-A	NC	C	C	NC	NA	NA	NC	NA	NA	C	NA	C	NA	NA	NA	Nonconforming
L-3-B	NC	C	C	NC	NA	NA	NC	NA	NA	C	NA	C	NA	NA	NA	Nonconforming
L-3-C																
L-3-D																
L-3-E	NC	C	C	NC	NA	NC	NC	NA	CC	C	NA	C	CC	CC	CC	Nonconforming
L-3-F	C	C	C	NC	NA	C	CC	NA	C	C	C	C	C	C	C	Nonconforming
L-3-G																
L-3-H																
L-3-I	C	C	C	C	NA	C	C	NA	C	C	C	C	C	C	C	Conforms
L-3-J																
L-3-K																

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Table 9. Engineering Assessment of Acceptable Strategies

No.	Engineering Considerations	Conclusions	Broad Strategy Designator
L-3-I	**Compatibility with strategies for other "local" hazards** For example, a tank ventilation capability will be required for flammable gas control and the system will contain filtration--therefore part of Strategy L-3-I will exist and could be considered for the boiling hazard/event. However, unique characteristics must be addressed such as effects of hot nitric acid vapors on the broader strategies.	This strategy is compatible with the need for tank filtered-ventilation for controlling other hazards associated with this process element. The tank ventilation system functional requirements are also a function of the other mitigation functions required to be achieved by this system.	TBD
	Compatibility with area-wide strategies For example, is there merit in using on cooling system for all tanks with significant decay heat?	TBD	TBD
	Compatibility with plant-wide strategies For example, is there merit in a plant-wide vessel ventilation system or a plant-wide confinement arrangement?	TBD	TBD
	Engineering Considerations Are there engineering feasibility, cost, operability, maintainability, testing, inspection, or other issues that favor or discourage this strategy?	TBD	
	Secondary Hazards Does the strategy produce additional hazards either directly (isolation of an area in which flammable gas is generated) or indirectly by adverse effects on other hazards control provisions?	None identified	

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Table 10. Selected Strategy Elements and Provisions

Selected Strategy Description and Rationale

The strategy selected is based on L-3-I of Table 8, which conforms to the top-level principles, including the provision of a high level of assurance that the strategy will be effective when fully engineered and implemented. This strategy is also compatible with the engineering assessment at the "local" level, which anticipates the need for a tank ventilation system to accommodate other hazards (such as radiolytic production of hydrogen). The strategy is a diverse strategy that provides both prevention and mitigation through two additional independent active systems; one for backup heat removal and one for filtered-ventilation of the tank headspace. The strategy also includes a primary heat removal system that is of sufficient quality and is operated/maintained in a condition that makes the boiling event an "unlikely" ($< 10^{-2}$ per year) event. The strategy relies on human activation and monitoring of the backup heat removal system, and human monitoring of the continuously operating tank ventilation system. The human element of the strategy is acceptable because the complexity of the anticipated actions is low and well within standard practice and the time interval for performing the anticipated actions is days. Because of the unique character of the heat removal problem (may require special features to guard against leaks of Cs/Tc concentrate into the cooling system if coils internal to the tank are used), a dedicated backup heat removal system is included as part of the strategy. The strategy includes a tank ventilation system that is common to a number of tanks (however, open issues related to the filtration of certain volatile Tc compounds may, on further engineering evaluation, lead to a dedicated ventilation system for this tank).

Selected Strategy Elements	Element No.	Strategy Element Provisions	Key Provision No.
Primary active cooling system	L-3-I-1	Cooling fluid	L-3-I-1-a
		Cooling system piping	L-3-I-1-b
		Cooling system heat exchangers	L-3-I-1-c
		Cooling system pump	L-3-I-1-d
		Power supply	L-3-I-1-e
		I & C	L-3-I-1-f
		Other	L-3-I-1-g
Independent backup active cooling system	L-3-I-2	Cooling fluid	L-3-I-2-a
		Cooling system piping	L-3-I-2-b
		Cooling system heat exchangers	L-3-I-2-c
		Cooling system pump	L-3-I-2-d
		Power supply	L-3-I-2-e
		I & C	L-3-I-2-f
		Other	L-3-I-2-g

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Active, continuously operating tank ventilation system	L-3-I-3	Ducting	L-3-I-3-a
		Filters	L-3-I-3-b
		Fans	L-3-I-3-c
		Power supply	L-3-I-3-d
		I & C	L-3-I-3-e
		Other	L-3-I-3-f
Human action activation and monitoring	L-3-I-4	Cooling status instrumentation and display	L-3-I-4-a
		Power supply	L-3-I-4-b
		Procedures	L-3-I-4-c
		Training	L-3-I-4-d
		Other	L-3-I-4-e

Table 11. Feature/Provision Functional Requirements

Provision No.	Capability	Reliability	Special Considerations
L-3-I-1-a	Consistent with heat transport of 26 kW up to 100^{o}C and with high gamma exposure	Consistent with an overall reliability of preventing boiling (or significant vapor production) of at least 0.99	If internal to the Cs/Tc Product Storage Tank, needs to be compatible with the tank contents in case of leakage
L-3-I-1-b	Same as provision "a"	Same as provision "a"	If internal to the Cs/Tc Product Storage Tank, needs to be compatible with the tank contents (nitric acid, etc.)
L-3-I-1-c	Same as provision "a" except without radiation field	Same as provision "a"	None identified
L-3-I-1-d	Same as provision "c"	Same as provision "a"	None identified
L-3-I-1-e	Same as provision "c"	Same as provision "a"	None identified
L-3-I-1-f	Same as provision "c"	Same as provision "a"	Some instruments may be in high rad field
L-3-I-1-g			
L-3-I-2-a	Consistent with heat transport of 26 kW up to 100^{o}C and with high gamma exposure	Consistent with an overall reliability of preventing boiling (or significant vapor production) on demand of at least 0.99	If internal to the Cs/Tc Product Storage Tank, needs to be compatible with the tank contents in case of leakage
L-3-I-2-b	Same as provision "a"	Same as provision "a"	If internal to the Cs/Tc Product Storage Tank, needs to be compatible with the tank contents (nitric acid, etc.)
L-3-I-2-c	Same as provision "a" except without radiation field	Same as provision "a"	None identified
L-3-I-2-d	Same as provision "c"	Same as provision "a"	None identified
L-3-I-2-e	Same as provision "c"	Same as provision "a"	None identified
L-3-I-2-f	Same as provision "c"	Same as provision "a"	Some instruments may be in high rad field
L-3-I-2-g			
L-3-I-3-a	TBD--need to consider other hazards such as hydrogen generation	Consistent with an overall unreliability of the strategy of $<10^{-6}$--- given the first two elements provide an unreliability of 10^{-4}, the mitigation reliability need to be at least 0.99	Nitric acid vapors and moisture

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Provision No.	Capability	Reliability	Special Considerations
L-3-I-3-b	Decontamination factor of at least 100 and perhaps more depending on other hazards being controlled by the same tank ventilation system	Same as provision "a"	Decontamination of Tc volatile compounds may require special features. Also, nitric acid vapors and moisture
L-3-I-3-c	Same as provision "a"	Same as provision "a"	Nitric acid vapors and moisture
L-3-I-3-d	Same as provision "a"	Same as provision "a"	None identified
L-3-I-3-e	Same as provision "a"	Same as provision "a"	None identified
L-3-I-3-f			
L-3-I-4-a	TBD--need to consider human actions associated with operations, etc. as well as for the control of other hazards/events	Consistent with the needed reliability of the cooling and ventilation functions (0.99) as well as the reliability that may be required by human actions to control other hazards/events.	Time to perform human actions associated with the control of the L-3 hazard/event is days.
L-3-I-4-b	Same as provision "a"	Same as provision "a"	None identified
L-3-I-4-c	Same as provision "a"	Same as provision "a"	Time to perform human actions associated with the control of the L-3 hazard/event is days.
L-3-I-4-d	Same as provision "a"	Same as provision "a"	None identified
L-3-I-4-e			

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ESSENTIAL PROCESS STEP 5--Identification of Standards

In this exercise, the selection of specific standards was not performed because substantially more engineering expertise is needed for this step than was available to the small team performing the exercise. Instead, the focus was placed on the approaches that would be used to make the standards selections. Table 12 is the tabular format that would be used as a means of linking the selected standards (or specific portions thereof) to the features/provisions of the selected control strategy, L-3-I.

Table 12. Selected Standards and Associated Rationale for Each Hazard Control Feature/Provision

Provision No.	Standards Selected	Selection Rationale
L-3-I-1-a		
L-3-I-1-b		
L-3-I-1-c		
L-3-I-1-d		
L-3-I-1-e		
L-3-I-1-f		
L-3-I-1-g		
L-3-I-2-a		
L-3-I-2-b		
L-3-I-2-c		
L-3-I-2-d		
L-3-I-2-e		
L-3-I-2-f		
L-3-I-2-g		
L-3-I-3-a		
L-3-I-3-b		
L-3-I-3-c		
L-3-I-3-d		
L-3-I-3-e		
L-3-I-3-f		
L-3-I-4-a		
L-3-I-4-b		
L-3-I-4-c		
L-3-I-4-d		
L-3-I-4-e		

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